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# Progress on Converting a NIF Quad to Eight, Petawatt Beams for Advanced Radiography

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**Abstract.** We are converting a quad of NIF beamlines into eight, short-pulse (1-50 ps), petawatt-class beams for advanced radiography and fast ignition experiments. This paper describes progress toward completing this project.

## 1. Introduction

To diagnose the high-density core of an imploding fusion capsule on a time scale that is relevant for successfully optimizing target and driver parameters,  $\sim 100$  keV, ps x-ray backlighters are required. We are converting four (one quad) of the NIF laser system's 192 long-pulse beamlines to eight, petawatt-class, high-intensity beams. Each of these eight beams can be independently timed, pointed and focused onto high-Z, x-ray-backlighters in the vicinity of the cryogenic ignition target, producing a multi-frame, short-pulse x-ray movie of the cryogenic fusion target during the compression and ignition phases. We call this x-ray generation system the Advanced Radiographic Capability (ARC)[1]. In addition to generating short-pulse x-rays to support advanced radiography for fusion and other high energy density science experiments, the eight beams may be combined into a single pulse on target to explore fast ignition physics in the 10 kJ, 5 ps regime.

## 2. Description

We will convert a quad of long pulse (ns-scale) beamlines of the NIF laser system [2] into ps-scale, high intensity beamlines using conventional chirp-pulse amplification techniques [3], adapted to the overall architecture of the NIF laser system. Figure 1 shows the architecture for converting a NIF quad to ARC. ARC hardware through the front end has been built and tested; the rest is in various stages of design and fabrication.

### 2.1. ARC front end

The seed pulse for ARC is produced by a Yb:doped fiber mode-locked oscillator [4]. We stretch the pulse to several ns using a chirped-fiber-Bragg-grating (CFBG) that is supplied by the University of Southampton. We split the output of the CFBG to make two separate fiber beamlines. The positive

group delay produced by the CFBG is balanced by the fixed negative group delay in the large final compressors and small, adjustable compressors, or pulse width controllers (PWCs) that are rack-mounted in the NIF master oscillator room. [4] We amplify the output energy in the fiber front end up to 1 nanoJoule before transporting the pulse to the laser bay.

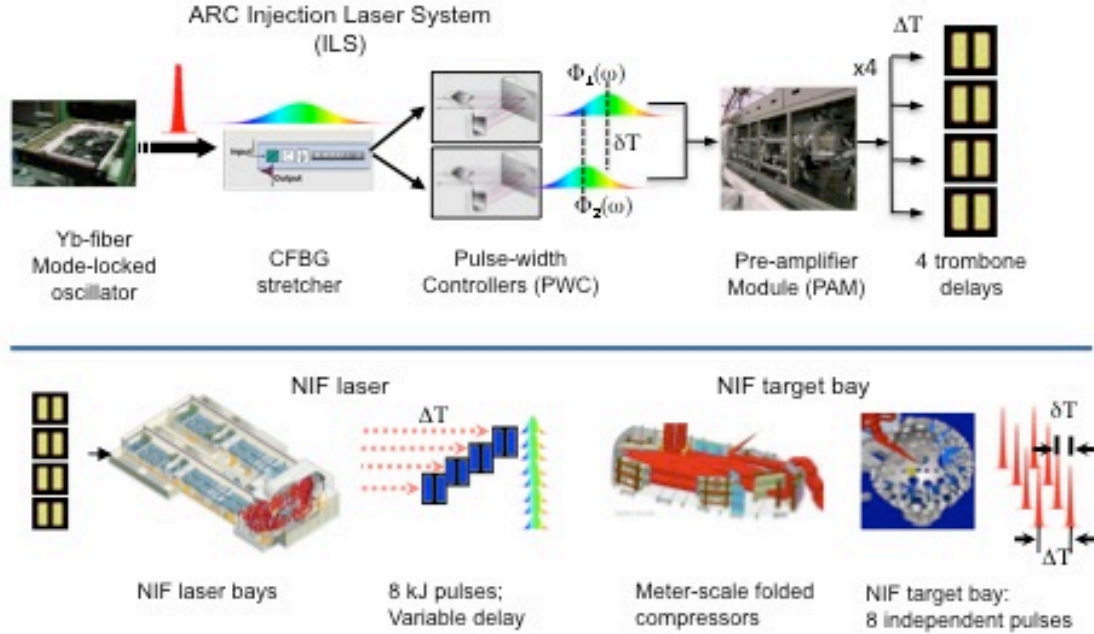


Figure 1. Layout shows the principal subsystems for the conversion of a NIF quad to ARC.

In the laser bay the two fiber outputs from the ARC fiber front end seed identical regenerative amplifiers that include intracavity birefringent filters to tailor the pulse spectrum. The two regen outputs are spatially shaped and combined to form a split beam pair whose outer perimeter is the same size as a NIF beam. The ARC split beam pair will be amplified in a modified NIF chain up to the kJ level.

## 2.2. Pulse width, timing and dispersion balance

The two fiber beamlines are split after the CFBG and go to two different PWCs. We can separately adjust the group delay and timing,  $\delta T$ , between the stretched pulses in the two fiber systems by adjusting the grating spacings, roof mirror positions or by adding fiber jumpers for larger delays. The two fiber outputs are combined after the regens into a single, split-beam aperture to be amplified through the NIF chain. The amplified, split-beam at the PAM output will be split 4 ways in the Preamplifier Beam Transport System (PABTS) before being injected into the four beamlines of the NIF quad. The ARC PABTS will have two-meter long trombone sections with stepper motor controls to adjust the delays,  $\Delta T$ , between the beamlines in the quad. Finally each of the eight, amplified ARC split beams is sent to a four grating, folded compressor in one of the large vessels in the target bay. To generate eight identical pulses at the ARC output, dispersion must be carefully balanced in each beamline. We developed a group delay diagnostic that measures dispersion in the separate dispersive systems, e.g. CFBG, PWC, transport fiber, grating compressors. [5]

## 2.3. Target bay systems

The four outputs from the NIF quad can produce four, ns-scale pulses, or eight, ARC, ps-scale pulses. When seeded by the ARC front end the output pulses are picked off in the switchyard by insertable mirrors and directed to two large vacuum compressor vessels placed in the target bay on the 29' floor.

Each vessel houses four, folded grating compressors on two elevations that compress the amplified ARC pulses to ps widths. For example, on the lower level of compressor vessel one (CV1) are pairs of large (455 mm X 910 mm), side-by-side, multi-layer dielectric gratings [6] for the split beam. Each grating in the pair disperses one of the split beams.

After compression, four large mirrors direct the output of each split beam to a separate target for generating ps x-rays to backlight experiments at the center of the NIF target chamber. The first of the four output turning mirrors leaks a small fraction of the light to send to a diagnostics system that measures the spatial and temporal characteristics of the compressed ARC pulse. The third output turning mirror is a 45 degree, off-axis parabola with a  $\sim 9$  meter focal length to focus ARC at the target chamber center. After the parabola a pair of side-by-side flat mirrors (one for each split beam) with independent linear adjustment along the propagation axis, plus two-axis angular adjustment, directs the focused pulses to separate targets in the vicinity of target chamber center. Finally a thin, disposable debris shield protects the final optics from high velocity target debris.

### 3. Requirements and performance

The top level requirements for ARC, shown in Table 1, are determined by user needs and laser and optical system limitations. These top-level requirements are flowed back to the front end to determine the requirements at each subsystem interface. For example, the peak irradiance is driven by the need to generate enough 100 keV x-rays to produce spatially resolved images of the imploding capsule in the vicinity of “bang time”. However this peak value is limited by damage on the final grating, parabola, and final turning mirror at the specified pulse width. The damage values are determined from measurements of coating witness samples and deterministic models [7] for damage growth. To estimate encircled energy at the ARC focus we use NIF and CEA propagation codes [8,9]. Detailed interferograms from the manufactured ARC gratings, wavefront files for large mirrors, and data from the NIF output sensor package [2] at ARC energy levels provide inputs for the propagation codes.

**Table 1.** Top level requirements for ARC.

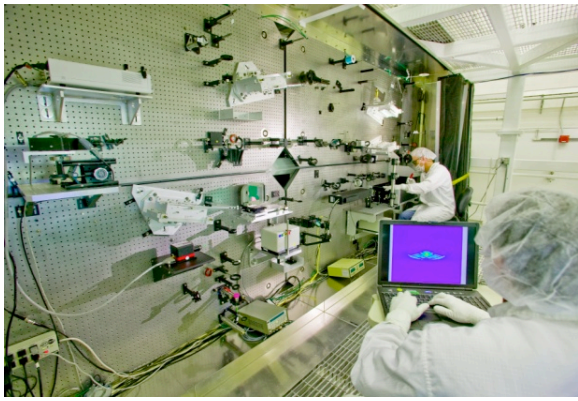
Description	Value	Basis
Peak irradiance	$>10^{18}$ W/cm <sup>2</sup> @ 2 ps	sufficient 100 keV x-rays for
Encircled energy	$>80\%$ in 300 $\mu\text{m}$ diameter circle at TCC	radiography missions
Pre-pulse contrast	$< -70$ dB in power $< 10^{-5}$ in energy	maintain target integrity
Pulse width range	1-50 ps	satisfy different HEDS missions
Pointing stability	$< 75$ $\mu\text{m}$ rms	consistent with current NIF requirements
Timing jitter relative to NIF average	$< 30$ ps rms	x-ray movie range for HEDS experiments
Timing adjustment relative to NIF	0-75 ns	
Back-scatter protection	$>10\%$ of output energy	Protect NIF laser system

### 4. Recent progress

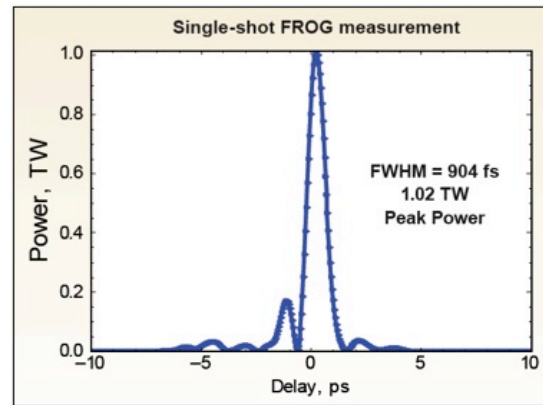
We have made some major modifications in the past year to better protect the ARC laser system from target back-reflections. We replaced the two final fiber amplifiers in the original design with two, high-bandwidth, regenerative amplifiers, boosting the energy of the ARC injection laser system from 100 mJ to 5 J. At the same time we will reduce the stored energy in the main NIF amplifier chain used for ARC by reducing the number of slabs in the main amplifiers from eleven to eight. To further protect the front end from backward propagating energy from the target, we plan to replace one of the

amplifier slabs with a polarizer and triple-pulse the plasma electrode Pockels cell to further reduce backward propagating 1053 nm light. These changes should protect the laser against >10% of the total forward energy returning from the target.

We built a four grating, folded compressor at the output of the ARC Injection Laser Test facility, shown in Figure 2, to demonstrate dispersion balance, measure temporal fidelity, amplified spontaneous emission, focal spot quality, test the temporal diagnostics, and diagnose systems issues in the ARC front end. The compressor gratings are 100 mm X 200 mm MLD gratings that are identical in line spacing to the ARC A gratings. We double pass the compressor to reduce the footprint while duplicating the group delay of the ARC compressor. Figure 3 shows a 1 TW pulse measured at the output of the ARC test facility using our single-shot SHG FROG. The small bumps at the front of the pulse are due to imperfect balance of the third-order dispersion in the front end plus group delay ripple from the CFBG.



**Figure 2.** ARC Injection Laser Test Facility.



**Figure 3.** Power measurement derived from energy and temporal diagnostic at the ARC Injection Laser Test Facility output.

Many of the major systems for ARC are complete, including the ARC fiber front end, the triple-pulse PEPC, most of the large optics including the gratings and parabolas, and the large vacuum vessels for the compressors and parabolas.

### Acknowledgments

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